FORM PTO-1390 (REV. 9-2001) U S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER: **P29.41290X00 filed March 27, 2002**

U S APPLICATION NO (If known, see 37 CFR 1 5): **10/089155**

INTERNATIONAL APPLICATION NO	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/JP00/06711	**September 28, 2000**	**September 28, 1999**

TITLE OF INVENTION
MAGNETIC RESONANCE IMAGING DIAGNOSTIC APPARATUS AND METHOD THERFOR

APPLICANT(S) FOR DO/EO/US **SHIMIZU, HIROMICHI**

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.

2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.

3. ☐ This express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.

4. ☒ The US has been elected by the expiration of 19 months from the priority date (Article 31).

5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2)))
   a. ☐ is transmitted hereto (required only if not communicated by the International Bureau).
   b. ☒ has been communicated by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office(RO/US)

6. ☒ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☒ is attached hereto.
   b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).

7. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. ☐ are attached hereto (required only if not communicated by the International Bureau).
   b. ☐ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☐ have not been made and will not be made.

8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).

9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).

10. ☐ An English language translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11 to 20 below concern document(s) or information included:

11. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.

12. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.

13. ☐ A FIRST preliminary amendment.

14. ☐ A SECOND or SUBSEQUENT preliminary amendment.

15. ☐ A substitute specification.

16. ☒ A change of power of attorney and/or address letter.

17. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.

18. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).

19. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).

20. ☒ Other items or information: **Figs. 1,2a-2d,3-10, Credit Card Payment Form, International Publication Number WO 01/22879**

U.S. APPLICATION NO (If known, see 37 CFR 1.5)	INTERNATIONAL APPLICATION NO	ATTORNEY'S DOCKET NUMBER
10/089155	PCT/JP00/06711	529.41290X00

21. The following fees are submitted.

	CALCULATIONS PTO USE ONLY
BASIC NATIONAL FEE (37 CFR 1.492(a) (1) - (5)):	
☐ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO **$1040.00**	
☒ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO **$890.00**	
☐ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO **$740.00**	
☐ International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) **$710.00**	
☐ International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) **$100.00**	
ENTER APPROPRIATE BASIC FEE AMOUNT =	**$890.00**
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE	
Total Claims	**18** - 20 =	**0**	x **$18.00**	$
Independent Claims	**3** - 3 =	**0**	x **$84.00**	$
MULTIPLE DEPENDENT CLAIMS(S) (if applicable)	**280**		+ **$280.00**	**$280.00**
			TOTAL OF ABOVE CALCULATIONS =	**$1,170.00**
☐ Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by ½.				$
			SUBTOTAL =	$
Processing fee of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)).				$
			TOTAL NATIONAL FEE =	**$1,170.00**
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) **$40.00** per property				**$40.00**
			TOTAL FEES ENCLOSED =	**$1,210.00**
			Amount to be refunded:	$
			charged:	$

a. ☐ A check in the amount of $_____ to cover the fees is enclosed.

b. ☐ Please charge my Deposit Account No **01-2135** in the amount of $_____ to cover the above fees. A duplicate copy of this sheet is enclosed

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposition Account No **01-2135**. A duplicate copy of this sheet is enclosed

d. ☒ Fees are to be charged to a credit card **WARNING:** Information on this form may become public. **Credit card information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

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MAGNETIC RESONANCE IMAGING DIAGNOSTIC APPARATUS AND METHOD THEREFOR

FIELD OF THE INVENTION

The present invention relates to a magnetic resonance imaging diagnostic apparatus (hereinafter this is referred to MRI apparatus), particularly to an MRI apparatus having a spectroscopic imaging function.

BACKGROUND OF THE ART

A spectroscopic imaging method using a magnetic resonance diagnostic apparatus for medical use (MRI) (hereinafter, this is referred to MRSI method) is a method for imaging a distribution of specific chemical component in the living body. This method can acquire not only an anatomical information, which is acquired in an ordinary MRI, but also can acquire a chemical information of carbohydrate metabolism or an energy metabolism or the like. So it is useful for diagnosis at first stage of disease.

Various kind of MRSI methods are attempted such as 3D-CSI method for measuring a chemical shift as a temporal coefficient, but a method using proton (^{1}H nucleus) is generally used in an MRI apparatus for a clinical use. 3D-CSI method includes phase encoding of a spatial information in direction x and y, and a spectrum information is encoded with time progress in a signal measurement.

In MRSI to measure proton, signals of water and fat disturb because they are included in the living body more than 2 to 4 orders in comparison with metabolic materials. So it is necessary to combine a technique to suppress them. Prior art will be described referring to Fig. 9 and Fig. 10. In the prior art, the spectrum of water is selectively excited in preprocessing by CHESS pulse 31, subsequently gradient magnetic field 33 is applied to dephase a magnetization of water so as not to produce signal. Furthermore, after having excited the slice perpendicular to the imaging section (fat part) with pulse 32, gradient magnetic field 34 is applied to dephase this magnetization in this slice (OVS : Outer Volume Suppression). This process is repeated to cover all of fat region with changing slice. After this preprocessing is completed, a spectroscopic imaging is performed.

An example will be described using a transaxial slice of head in Fig.9. Excitation and dephasing are performed from slice 1 to 8 with changing the

direction for covering head surface with nearly ellipse shape. Eight pieces of slice are used in order to cover subcutaneous fat in fig. 9. But usually 4 to 8 slices are used.

In this traditional fat suppression method, it was difficult to cover a fat region precisely because a fat system is covered with plural number of rectangle. And it was difficult to suppress fully the signal from fat. On the other hand, it is necessary to increase number of rectangle for covering fully the fat system. And it was troublesome to set the rectangular region. In addition, if the number of rectangle is increasing, preprocessing will have to be longer. And recovery of water magnetization will be generated due to the longitudinal relaxation, and suppression of water will be insufficiently.

Furthermore in 3D-CSI method, at least double phase encode loop is used because spatial coordinate information of 2 or 3 axes are given in the signal, so it takes a long time to measure. But in a traditional fat suppression method, it takes about 20 to 50 ms for preprocessing. So it includes a problem that imaging time is elongated.

Thus the object of the present invention is to provide an MRI apparatus capable of realizing an MRSI method that a useless signal is sure to be suppressed and there is no elongation of measurement time.

DISCLOSURE OF THE INVENTION

In order to solve such problems in this invention, an MRI apparatus for performing spectroscopic measurement includes a function with the application of swing gradient magnetic field of the direction two or three axes together with a predetermined high frequency magnetic field (RF). This makes no need of fat suppression process in phase encode loop, and a signal from fat system can be greatly reduced.

A technique of performing a spatial selective excitation with the combination of swing gradient magnetic field and RF wave form calculated from form function of excitation are precisely described in an article "A k-Space Analysis of Small-Tip-Angle Excitation", J.Magn.Reson., 81, 43-56 (1989) or the like, by the author J. Pauly, D. Nishimura and A.Macovski. But an MRI apparatus of the present invention is to provide means for taking in techniques of this spatial selective excitation concretely to an MRSI measurement.

That is to say, an MRI apparatus of the present invention comprises magnetic field generation means for generating static magnetic field, gradient magnetic field and high frequency magnetic field (RF) to the object to be examined respectively, and detection means for detecting an magnetic resonance signal generated from the object to be examined, and image reconstruction means for image reconstructing with an magnetic resonance signal detected, and display means for displaying a reconstructed image, and control means for controlling said each means.

Control means comprises means for setting a desired region of interest (ROI) in a predetermined region of the object, and means for calculating modulation wave form of RF excited selectively in this ROI. And control means performs controlling the application of an RF pulse modulated with modulation wave form and swing gradient magnetic field of the direction of two or three axes simultaneously, and acquires signals including a spectrum information about the predetermined region of the object.

Only the interior of ROI with an arbitrary shape being looked at is excited and the signal is acquired. So effect of fat and water from the exterior of ROI can be effectively suppressed. Thus fixed quantity of spectrum can be improved and accuracy of diagnosis can be improved. In addition, the excitation pulse is selective in region, so it is no need to irradiate fat suppression RF pulse in preprocessing for performing phase encode repeatedly. So time for preprocessing can be shortened. As a result recovery of water signal can be reduced.

In the MRI apparatus of the present invention, means for setting ROI displays a slice image obtained at desired slice position as a scout image, and function to set ROI on the scout image displayed is interactively.

Means for calculating an RF waveform concretely makes an excitation form function from the shape of ROI, and calculates a modulated waveform of high frequency magnetic field by two-dimensional Fourier transformation of this excitation form function in nearly real time.

This RF waveform for selective excitation is different from the shape of ROI. But by previously imaging a scout image and displaying it, ROI is able to set interactively on this scout image. Accordingly an arbitrary ROI shape can be easily set. In addition, a modulated RF waveform is generated by performing two-dimensional Fourier transformation with computer to the shape of set ROI. So an RF waveform corresponding to ROI can be acquired

with nearly real time. And an MRSI measurement can be performed soon after setting of ROI.

Moreover a preferred embodiment of an MRI apparatus in the present invention, control means sets the smallest rectangular region including ROI, and determines an image matrix size according to this rectangular region.

An image matrix size is the size of image data for expressing the number of pixel (or voxel), which is the number of line × row, arranged in two-dimensional or three-dimensional. It is defined with the number of gradient magnetic field encode for encoding spatial information. Accordingly, it is no need to make the size of image matrix so large by defining it with the smallest rectangle for covering the shape of ROI. As a result it is no need to repeat useless phase encode. And measurement time of MRSI can be shortened.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a flow chart showing procedure in the embodiment of the present invention.

Fig.2 is a view showing method of setting ROI interactively, and an matrix.

Fig.3 is a figure showing one example of sequence applied to the present invention.

Fig.4 is a view showing whole composition of MRI apparatus of the present invention.

Fig.5 is a view showing another example of sequence applied to the present invention.

Fig.6 is a flow chart showing procedure according to another embodiment of the present invention.

Fig.7 is a view showing another example of sequence applied to the present invention.

Fig.8 is a view showing another example of sequence applied to the present invention.

Fig.9 is a view showing a traditional fat suppression method.

Fig.10 is a view showing sequence with the combination of water suppression and fat suppression in traditional type.

THE BEST MODE FOR CARRYING OUT THE INVENTION

The present invention will be described precisely referring to Fig.1 or Fig.8. Fig. 4 is a schematic block diagram of an MRI apparatus applied to the present invention. This MRI apparatus comprises static magnetic field generating magnetic circuit 402 for generating uniform static magnetic field B0 in the interior of the object to be examined 401, gradient magnetic field generation system 403 for generating gradient magnetic field Gx, Gy, Gz for changing those intensity linearly to three direction x, y and z being perpendicular to each other, transmitter system 404 for generating high frequency magnetic field, detection system 405 for detecting nuclear magnetic resonance signal generated from the object, signal processing system 406, computer 408 for performing calculation of image reconstruction and controlling the whole apparatus, sequencer 407 for controlling gradient magnetic field generation system 403, transmitter system 404 and detection system 405 with the order from computer 408, operation part 421 for sending necessary order to signal processing system 406 and computer 408.

Static magnetic field generation magnetic circuit 402 comprises an electromagnet or a permanent magnet. And the object 401 is accommodated in the space of its static magnetic field.

Gradient magnetic field generation system 403 comprises gradient magnetic field coil 409 with three axes, power supply 410 for supplying current to the gradient magnetic field coil. And it generates a linear gradient magnetic field for applying spatial information to the magnetic resonance signal and swing gradient magnetic field when ROI is selectively excited.

Transmitter system 404 comprises synthesizer 414 for generating predetermined high frequency pulses, modulator 412 for modulating high frequency pulse generated from synthesizer 411, electric power amplifier 413, and transmitter coil 414 a. Modulation wave form modulated by this modulator 412 is calculated and saved by computer 408 as the following procedure and given from sequencer 407. High frequency magnetic field is generated in the interior of the object 401 to excite a nuclear spin, by supplying high frequency pulse modulated with predetermined modulation waveform to transmitter coil 414a. An excited nuclear spin is usually use ^{1}H. But other nuclear such as ^{31}P, ^{12}C or the like are also used.

Detection system 405 comprises receiver coil 414b for receiving nuclear magnetic resonance signals emitted from the object 401, amplifier 415, quadrature phase detector 416, and A / D converter 417. Nuclear

magnetic resonance signals, which are received with receiver coil 414b and amplified with amplifier 415, is input to computer 408 after quadrature detection and A/D conversion.

Transmitter coil 414a and receiver coil 414b can be separated as shown in the figure. But the coil combined them can be used.

Computer 408 reconstructs an image corresponding to density distribution of nuclear spin, distribution of relaxation time, spectrum distribution or the like, and display them to CRT display 428. Operation part 421 is composed within computer 408 and inputs order, which is necessary for performing program of processing in this MRI apparatus and various kinds of setting to computer 408. Processing performed through this operation part 421 is processing for setting ROI (region of interest) to the predetermined region of the object, processing for determining image matrix size in accordance with ROI, processing for calculating RF modulation wave form generated in transmitter system 404 based on the shape of ROI. Data in the middle or last of the calculation performed in this computer 408 is accommodated in memory 424 and 425.

Computer 408 controls gradient magnetic field generation system 403, transmitter system 404, and detection system 405 through sequencer 407 to perform the imaging with a predetermined imaging sequence.

Next MRSI measurement performed with these MRI apparatus will be described. And in the following described embodiment, the case that proton MRSI performed on the transaxial face (x-y face) of abdominal region is assumed. But another slice can be applied to this method. In addition, suppression of fat will be described as an example, but it is possible to suppress the spectrum other than fat.

Fig.1 is a flow chart of MRSI of the present invention. Fig.2 is a view showing the setting of ROI. Fig.3 is a view showing one embodiment of imaging sequence at MRSI method of the present invention.

In MRSI measurement of the embodiment a scout image is acquired to the desired slice before a spectroscopic measurement is performed (Fig.1, step 11). A scout image can be acquired by using a general imaging method of MRI such as FSE (Fast Spin Echo) method, EPI (Echo Planner Imaging) method. This selected slice is an arbitrary slice being included within the region of an object to be measured.

After having displayed this scout image to display, ROI of closed

region is set with mouse or the like so as to cover the desired region entirely without covering fat (step 12). Fig.2 is a view showing typically the scout image displayed, and 61 is an ROI input with mouse.

Thus after smoothing set ROI 61, 2 value function of interior of ROI being 1 and exterior of ROI being 0 are made to define form function D(x,y) (step 13). The shape of ROI can be specified with an arbitrary shape principally. However, the shape is more complex, the Fourier transformation D'(kx,ky) of form function D(x,y) includes more high frequency components that is the edge of k space component. So it is necessary to enlarge k space in the imaging after that. This means that amplitude of swing gradient magnetic field is large, and its application time is long. In this case it is difficult to equipment and imaging time has to be expanded. Accordingly, in inputting the shape of ROI, it is more practical to avoid making complex unnecessarily. In addition, the borderline of form function changes more sharply in rising up, fat region is suppressed sharply. But it is severe in amplitude characteristic and transient characteristic of gradient magnetic field. It is preferable to apply smoothing for 2 value function D(x, y) necessarily. For example, on the borderline of the value D changing from 0 to 1, it has a certain amount of width to decrease gradually from 1 to 0.

Next two dimensional Fourier transformation is performed on form function D(x,y) to generate function D'(kx,ky) of k space. By using this function D', RF waveform $B_1(t)$ is calculated with an equation (1) (step 14).

$$B_1(t)=D'(k_x(t),k_y(t)) \cdot | \gamma G(t) | \qquad \cdots(1)$$

Gradient magnetic field waveform Gx(t)、Gy(t) are predetermined to a imaging sequence of the imaging. For example, gradient magnetic field waveform Gx(t)、Gy(t) having the shape of spiral orbit converging from the edge of k space to start point with constant speed can be used. Specific example of these gradient magnetic field waveform Gx(t)、Gy(t) are shown in equation (2). These are sine wave or cosine wave, in which their amplitudes decrease linearly as a function of time.

$$Gx(t) = -A/\gamma T \ [2\pi n(1 - t/T)\sin 2\pi nt/T + \cos 2\pi nt/T]$$

$$Gy(t) = A/\gamma T \ [2\pi n(1 - t/T)\cos 2\pi nt/T - \sin 2\pi nt/T] \qquad \cdots(2)$$

In an equation (2), T/n is a rotation period of spiral of said space. In addition, A is a fixed number for defining size of spiral. n is usually about 10.

In addition, gradient magnetic field waveform Gx(t), Gy(t) is preferable to cover their orbit uniformly to the k space. Not only spiral, but also zigzag orbit such as used in EPI method can be used.

The RF waveform $B_1(t)$ calculated from these steps is saved to memory. And proceeding process is finished. Subsequently MRSI is performed by using RF excitation pulse modulated with this RF waveform $B_1(t)$ (step 15). In this step, amplitude of RF waveform B1(t) is arranged experimentally such that the maximum flip angle is 90° .

One embodiment of an MRSI imaging sequence of the present invention will be shown in Fig. 3. In this imaging sequence the spatial selective excitation is applied to 3D-CSI method. At first excitation pulse 71 is applied together with gradient magnetic field 74, 75 swinging to the x and y direction. And only the magnetization in the interior of two-dimensional region of the x-y plane is excited. Slice selective gradient magnetic field Gz is not applied in this case. The interior of ROI with nearly the shape of D(x,y) is excited with this excitation pulse. Accuracy of excitation form depends on the amount of high frequency component included in gradient magnetic field 74, 75 at k-space. Subsequently a spatial information of x, y is encoded to phase of magnetization by phase encode gradient magnetic field 76, 77. Refocus pulse 72 is applied together with slice selective gradient magnetic field Gz 73 to generate echo 78 after TE interval from the excitation. Thus the generated echo is received as a signal.

And waiting the recovery of longitudinal magnetization, next cycle is performed to repeat signal measurement with changing the phase encode amount. Three-dimensional Fourier transformation is performed to acquired echo signal as a function of phase encode (kx,ky) and time t to obtain a spectroscopic image (metabolic distribution image). In addition, it is desirable for MRSI method to use spin echo type as shown in the figure. Generally when frequency of excitation pulse is offset from resonance frequency, shape of an excited region and phase of transverse magnetization is affected with this offset. But in case of application of spin echo type, an influence by this offset is canceled by application of refocus 180° pulse 72.

The reconstructed image of metabolic distribution can be displayed to

CRT. But it is preferable to correct a spatial distribution by multiplying an inverse function of excitation form function D(x,y). Then a spatial variation of flip angle in excitation is corrected to obtain a metabolic distribution image having fixed quantities.

As thus described, in MRSI of the present invention it is no need of the OVS process for fat suppression. So the measurement time of 3D-CSI having double phase encode loop is shortened as same as it having no suppression process. And also fat suppression can be effectively.

Fig. 5 is a view showing another embodiment of 3D-CSI method of the present invention. This imaging sequence is different from that of shown in Fig.3 in the point that water suppression is used together. That is to say, a water spectrum is excited by known CHESS pulse 72 at each cycle of phase encode, and dephased with application of crusher gradient magnetic field 82. For CHESS pulse 81 Sinc function or Gaussian function is used. They are appropriately selected in consideration of the form of excited spectrum and application time or the like.

A measurement following the application of crusher gradient magnetic field 82 is the same as the imaging sequence shown in Fig.3. That is to say, the modulated waveform of RF pulse is calculated based on ROI interactively preset on the scout image, and saved to memory. And this RF pulse modulated by the modulated wave form is applied together with the swinging gradient magnetic field in the direction of x and y. And previously set ROI is excited selectively. And after the phase encoding, refocus pulse is applied to generate echo 78.

Previously described imaging sequence (two-dimensional MRSI) in Fig.3 and Fig.5 can be obtained a three-dimensional spectroscopic image by measuring with changing the slice position. In this case, when ROI deviates corresponding to the slice position, ROI can be moved in parallel from the reference position by giving phase modulation to RF waveform $B_1(t)$.

That is to say, when the position of ROI is shifted about x0, the phase modulation such as expressed in an equation (3) can be applied to RF.

$$B'_1(t)=B_1(t)e^{-ix0 \cdot k(t)} \qquad \cdots(3)$$

$$K(t)= -\gamma \int_t^T G(s)\, ds$$

In an equation (3), G(s) is a gradient magnetic field vector, and T is an application time of $B_1(t)$. Being specified shift x0 of the position on a scout image, the phase modulated waveform of RF pulse can be calculated with the equation (3). In this case the waveform of gradient magnetic field G(s) is predetermined.

Next another embodiment of MRSI according to the present invention will be described by using flow chart in Fig.6. Even in this embodiment, it is the same as those in FIg.1 from measurement of scout image (step 11) to calculation of RF waveform $B_1(t)$ (step 14). But in this embodiment, following the setting of ROI on the displayed scout image, the setting of image matrix size is performed (step 16,17). Thus at first, after ROI 61 is specified interactively on the image shown in Fig.2 (b), the smallest rectangular region 62 is automatically generated to cover the ROI (step 16). And the image matrix size, for example such as 16×12 is set in accordance with this rectangular region (step 17). Imaging (spatial selective excitation MRSI) is performed with phase encode step (kx,ky) corresponding to this image matrix size.

In the normal 3D-CSI method, phase encode step is usually performed with 16×16 or 32×32. As shown in 63 of Fig.3, its field of view is square. But in this embodiment, the image matrix is set corresponding to the smallest rectangular region 62 covering ROI. Accordingly it is no need to measure exterior pixels where magnetization is not excited, and repetition time of phase loop can be reduced. In addition, as shown in Fig.2 (c) and (d), it is preferable to rotate the direction of coordinate axis of image measuring matrix in accordance with inclination of ROI 61 that is the direction of rectangle. Thus region along the shape of ROI can be set, so it is possible to get the minimum number of repetition step. The others are the same as the embodiment shown in Fig.1.

In the above embodiment, the example of applying the invention to two-dimensional MRSI is described. But it is possible to apply the invention to three-dimensional MRSI in the presence of phase encode gradient magnetic field of slice direction. One example of three-dimensional MRSI imaging sequence will be shown in Fig.7. This imaging sequence includes water suppression (the application of CHESS pulse 81 and crusher gradient magnetic field 82) as same as the sequence shown in Fig.5, moreover phase

encode loop 91 in the slice direction is added to it. In addition, gradient magnetic field in the slice direction applied at the same time with refocus pulse 72 is slab selective gradient magnetic field, and it can be omitted.

In this three-dimensional MRSI also, the scout image is imaged in preprocessing, and ROI is set on the scout image. And the RF waveform is calculated from this shape function in the same way. And the image matrix size can be determined in the direction of x and y in accordance with the set ROI.

In addition, in the above-mentioned embodiment, spin echo type MRSI is described. And it is described that spin echo type is preferable for removing influence of offset to resonance frequency. But in case of measuring material with short T2, it is possible to apply with FID type.

This example will be shown in Fig. 8. In Fig.8, after the application of RF excitation pulse 71, phase encode magnetic field 76, 77 are applied in a short time. Then FID signal is measured immediately.

As thus described, MRSI with spatial selective excitation is described by using 3D-CSI method as an example. And spatial selective excitation can be performed with MRSI sequence by using another sequence such as EPI, FSE or the like.

According to the present invention described above, necessary part can be excited to obtain a signal with avoiding unnecessary part such as fat. Then metabolic image can be obtained for precisely excluding fat signals. In addition, as a result of no need to suppress fat in OVS of the preprocessing at each phase encoding. Accordingly the preprocessing can be shortened. And recovery of water due to longitudinal relaxation can be reduced. In addition, desired ROI is set interactively on a scout image to calculate automatically the RF excitation waveform from the ROI shape with calculator. And MRSI is performed soon after ROI is set. Furthermore, a minimum rectangular matrix is set in accordance with ROI to reduce useless measuring loop of MRSI. Then speedup of MRSI can be achieved.

These preferred embodiments of the present invention have been described referring to figures. It will be easily understood that the present invention can be varied without departing from the scope of the invention.

CLAIMS

1. Magnetic resonance imaging diagnostic apparatus comprising;

magnetic field generation means for generating static magnetic field, gradient magnetic field and high frequency magnetic field (RF) to said object to be examined respectively,

detection means for detecting magnetic resonance signal generated from said object,

image reconstruction means for image reconstructing said detected magnetic resonance signal,

display means for displaying said reconstructed image, and

control means for controlling said each means,

in which said magnetic field generation means generates gradient magnetic field to three directions being perpendicular to each other, and said control means applies swinging gradient magnetic field with predetermined amplitude at least two directions at the same time applying said high frequency magnetic field.

2. Magnetic resonance imaging diagnostic apparatus according to claim 1, wherein said control means includes means for setting region of interest (ROI) in predetermined region, and applies high frequency magnetic field for selectively exciting to said region of interest.

3. Magnetic resonance imaging diagnostic apparatus according to claim 1, wherein said control means controls to perform predetermined modulation to said high frequency magnetic field.

4. Magnetic resonance imaging diagnostic apparatus according to anyone of claim 1 to 3, wherein said control means applies high frequency magnetic field for selectively exciting water spectrum before applying said swing gradient magnetic field and gradient magnetic field for dephasing magnetization of water.

5. Magnetic resonance imaging diagnostic apparatus according to claim 2,

wherein said ROI setting means sets ROI on a slice image previously imaged and displayed on said display means.

6. Magnetic resonance imaging diagnostic apparatus according to claim 2, wherein said control means applies predetermined modulation based on said form of said ROI to said high frequency magnetic field.

7. Magnetic resonance imaging diagnostic apparatus comprising;

magnetic field generation means for generating static magnetic field, gradient magnetic field and high frequency magnetic field(RF) to said object to be examined respectively,

detection means for detecting magnetic resonance signal generated from said object,

image reconstruction means for image reconstructing said detected magnetic resonance signal,

display means for displaying said reconstructed image, and

control means for controlling said each means,

in which said control means comprises means for setting desired region of interest (ROI) in said predetermined region of said object, and means for calculating modulation wave form of high frequency magnetic field for selectively exciting said set ROI, and performs the control of applying the modulated high frequency magnetic field with said modulation wave form at the same time swing gradient magnetic field of two or three axis direction, and acquiring signal including spectrum information from determined region of said object.

8. Magnetic resonance imaging diagnostic apparatus according to claim 7, wherein said setting of ROI is performed by displaying slice image of desired slice to said display means as a scout image, and setting interactively said RIO on said displayed scout image.

9. Magnetic resonance imaging diagnostic apparatus according to claim 7 or 8, wherein said control means sets a minimum rectangular region for including said ROI, and determines an image matrix size in accordance with this rectangular region.

10. Magnetic resonance imaging diagnostic method for imaging distribution of specified chemical kind, comprising following steps;
(A) step for applying high frequency magnetic field to excite desired region,
(B) step for applying swing gradient magnetic field having predetermined amplitude to two of three directions being perpendicular to each other,
(C) step for applying phase encode gradient magnetic field with changing said intensity along the directions as same as those of swing gradient magnetic field applied at (B),
(D) step for applying gradient magnetic field for selecting slice in a direction different from that of swing gradient magnetic field applied at (B)
(E) step for applying high frequency magnetic field to reverse magnetization excited at step (A) at the same time step (D),
(F) step for detecting echo signal generated after a period, which is the same passing time from application of high frequency magnetic field at step (A) until application of high frequency magnetic field at step (E), after step (E).
(G) step for image reconstructing signal detected at step (F) and display the image.

11. Magnetic resonance imaging diagnostic method according to claim 10, wherein following step is performed before step (A).
(H) step for setting ROI in said predetermined region.

12. Magnetic resonance imaging diagnostic method according to claim 10, wherein following step is performed before step (A).
(I) step for applying modulation to high frequency magnetic field in step (A).

13. Magnetic resonance imaging diagnostic method according to claim 10, wherein following steps are performed before step (A)
(J) step for applying high frequency magnetic field to selectively excite water spectrum.
(K) step for applying gradient magnetic field to dephase magnetization of water.

14. Magnetic resonance imaging diagnostic method according to claim 10, wherein following step is performed before step (A)
(L) step for setting ROI on slice image previously imaged.

15. A magnetic resonance imaging diagnostic method according to claim 14, wherein following step is performed before step (A).
(M) step for modulating wave form based on the form of the ROI.

ABSTRACT

A spatial region in an imaged slice is two-dimensionally excited by applying an oscillating gradient magnetic field in two or three axial directions together with RF thus to conduct an MRSI. At a preprocessing step, a scout image is formed, an ROI is interactively set on the image, and an RF modulating waveform is automatically generated by two-dimensional Fourier transformation of an ROI shape, and a measurement matrix for the smallest square covering the ROI is automatically generated. By the MRSI, RF is modulated with the RF modulating waveform generated at the preprocessing step to measure an image matrix formed at the preprocessing step. Since an unnecessary portion such as a fat portion can be avoided precisely along its shape and only necessary portions are excited, a metabolic substance image from which unnecessary signals are completely eliminated can be generated. Since a desired ROI is inputted interactively on a scout image, the ROI can be simply set. The measurement time can be shortened by using a square measurement matrix.

Fig. 1

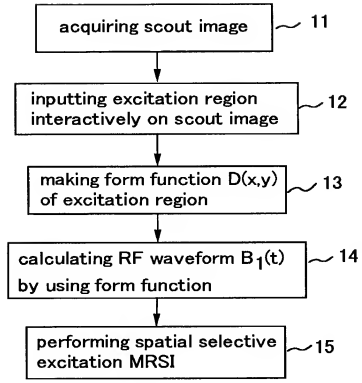
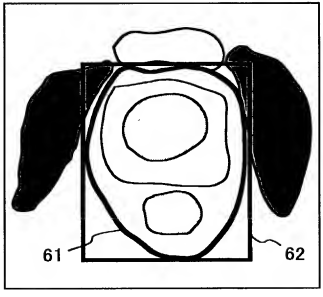

acquiring scout image
11
inputting excitation region interactively on scout image
12
making form function D(x,y) of excitation region
13
calculating RF waveform $B_1(t)$ by using form function
14
performing spatial selective excitation MRSI
15

Fig. 2



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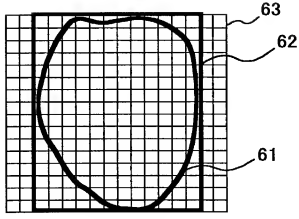

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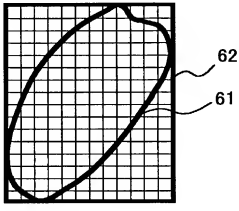

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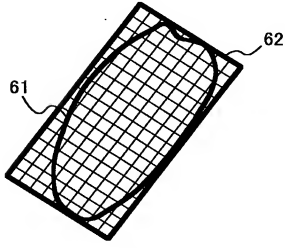


(d)

Fig. 3

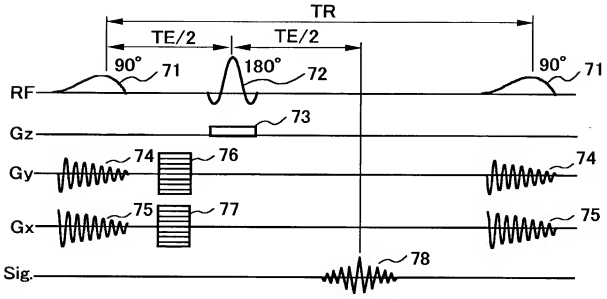
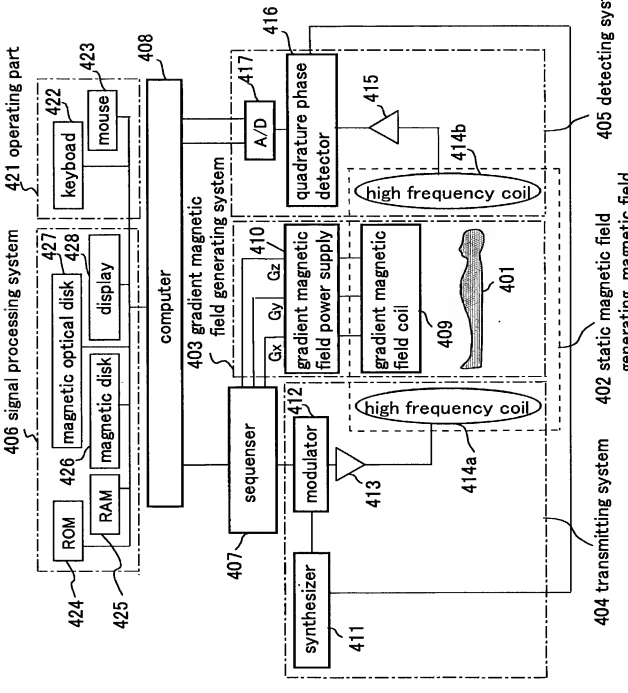


Fig.4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403 gradient magnetic field generating system
416
417
A/D
quadrature phase detector
415
414b
high frequency coil
410
Gz
Gy
Gx
gradient magnetic field power supply
gradient magnetic field coil
409
401
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synthesizer
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402 static magnetic field generating magnetic field
405 detecting system

Fig.5

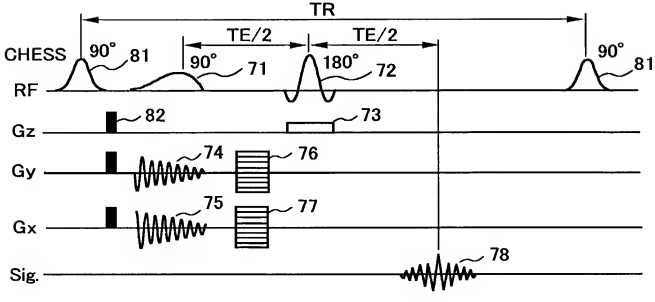
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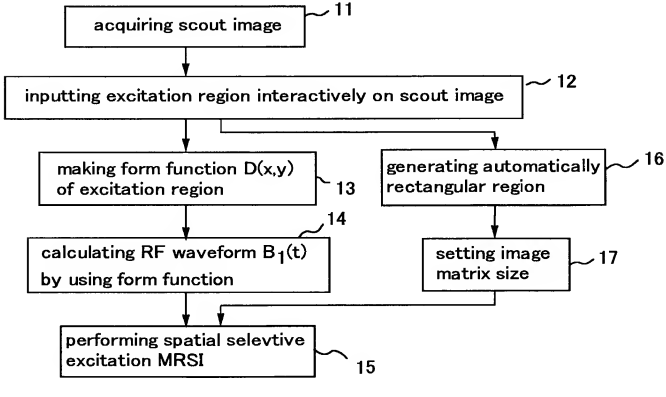
Fig.6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generating automatically rectangular region
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calculating RF waveform $B_1(t)$ by using form function
14
setting image matrix size
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performing spatial selevtive excitation MRSI
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Fig.7

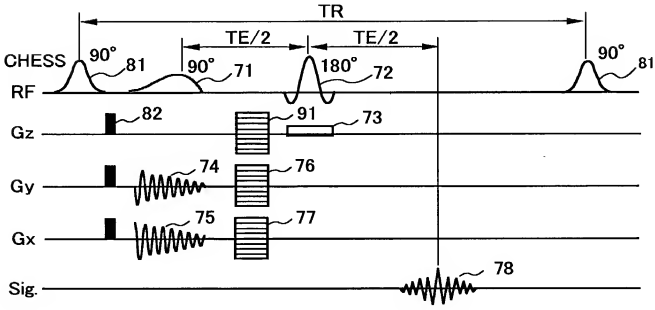
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Fig.8

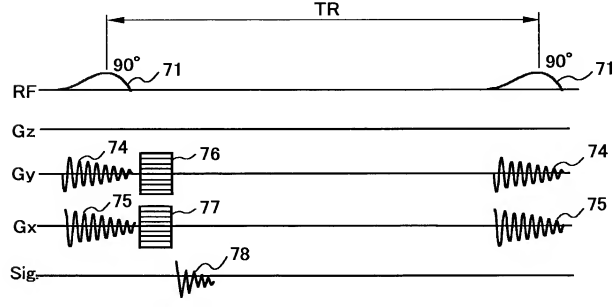
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Fig.9

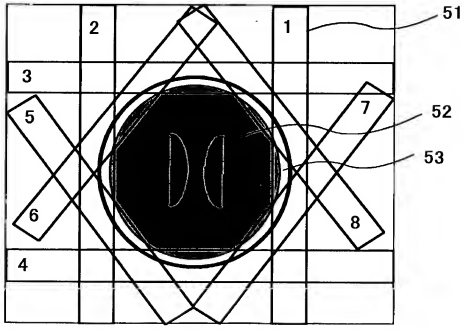
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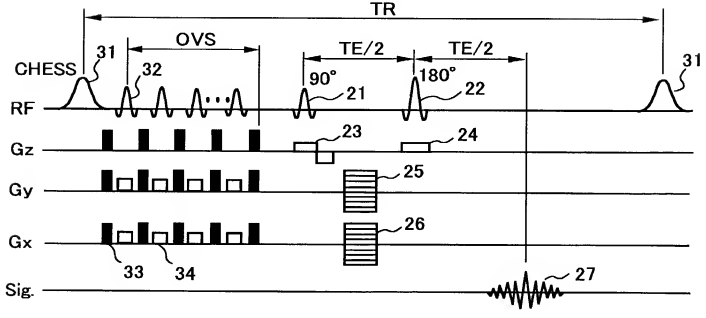
Fig.10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Gy
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Gx
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Sig.
27

Attorney's Docket No.: 529.41290X00

DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION

As a below named inventor, I hereby declare that: my residence, post office address and country of citizenship are as stated below, next to my name; I believe I am the original, first, and sole inventor (if only one name is listed below) or an original, first, and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

MAGNETIC RESONANCE IMAGING DIAGNOSTIC APPARATUS AND METHOD THEREFOR

the specification of which

___ is attached hereto.

_x_ was filed on **September 28, 2000** as
United States Application Number _____
or PCT International Application Number **PCT/JP00/06711**
and was amended on _____.
(if applicable)

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claim(s), as amended by any amendment referred to above. I acknowledge the duty to disclose all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119(a)-(d), of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)			Priority Claimed	
11/275286	JP	28/September/1999	X	____
(Number)	(Country)	(Day/Month/Year Filed)	Yes	No
_____	_____	_____	___	___
(Number)	(Country)	(Day/Month/Year Filed)	Yes	No

I hereby claim the benefit under title 35, United States Code, Section 119(e) of any United States provisional application(s) listed below

_____ _____
(Application Number) Filing Date

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, Section 112, I acknowledge the duty to disclose all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

_____	_____	_____
(Application Number)	Filing Date	(Status -- patented, pending, abandoned)

I hereby appoint: Donald R. Antonelli, Reg. No. 20,296; Melvin Kraus, Reg. No. 22,466; William I. Solomon, Reg. No. 28,565; Gregory E. Montone, Reg. No. 28,141; Ronald J. Shore, Reg. No. 28,577; Donald E. Stout, Reg. No. 26,422; Alan E. Schiavelli, Reg. No. 32,087; James N. Dresser, Reg. No. 22,973; Carl I. Brundidge, Reg. No. 29,621; Paul J. Skwierawski, Reg. No. 32,173; and Robert M. Bauer, Reg. No. 34,487, my attorneys; of ANTONELLI, TERRY, STOUT & KRAUS, LLP with offices located at 1300 North Seventeenth Street, Suite 1800, Arlington, Virginia 22209, telephone: (703) 312-6600, fax: (703) 312-6666; with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected herewith.

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Suite 1800
Arlington, VA. 22209

Direct all telephone calls and faxes to:

TEL: (703) 312-6600
FAX: (703) 312-6666

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Full Name of Second/Joint Inventor _____

Inventor's Signature _____ Date _____

Residence _____ Citizenship _____

(City, State) (Country)

Post Office Address _____

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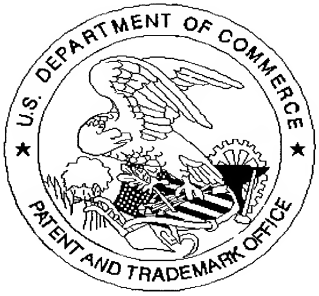

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☐ ***Scanned copy is best available.*** Figure 3 is dark.